# Proceedings of the Eighth International Workshop on Agglutinated Foraminifera

IWAF-8

Cluj-Napoca 2008

Edited by:
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# Proceedings of the Eighth International Workshop On Agglutinated Foraminifera
## (Cluj-Napoca, Romania, September 7-13, 2008)

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Published by

# Bathymetric distribution and ecology of agglutinated foraminifera along an inner neritic to upper bathyal transect in the Marmara Sea

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## ABSTRACT

The Marmara Sea is an intercontinental basin with two narrow and relative shallow straits connecting the Mediterranean Sea with the Black Sea. The Marmara Sea is characterised by the outflow of brackish shallow water from the Black Sea and saline bottom water inflow from the Mediterranean Sea. These oceanographic features determine the establishment of a sharp halocline, which leads to a permanent stratification generating low-oxygen and stratified conditions below a thin, well-mixed and highly oxygenated surface layer. This study documents for the first time the agglutinated foraminiferal assemblages of the Marmara Sea and their possible use as sensitive tracers of water masses. A total of 50 agglutinated species were identified belonging to 36 genera. Statistical analysis identifies three main assemblages that can be related to the bathymetry and in turn to the hydrological features of the water masses. The shallowest assemblages are characterised by both the lowest diversity and the highest dominance values induced by the strong influence of the Black Sea outflow that can be tolerated by only a limited number of species. High values of diversity have been identified at water depths shallower than 150 m, this increase has been associated with the inflow of Mediterranean countercurrent bringing more oxygenated and saline waters. The diversity values of the deepest assemblages show a complex pattern exhibiting a rapid increase and peaking at 225 m water depth. The lowest diversity corresponds to the lowest value of dissolved oxygen in the transect at 300 m water depth. A significant increase in diversity is observed from 300 m to 350 m water depth, linked to a rise in dissolved oxygen probably due to the presence of a Mediterranean-source bottom water undercurrent. This study confirms the suitability of using agglutinated foraminifera as tracers of water masses.

## INTRODUCTION

Foraminifera are single-celled organisms (protists), which have a long geological record and constitute the most diverse group of shelled microorganisms in modern oceans (Sen Gupta, 1999). The earliest benthic foraminiferal forms were single-chambered and had a detrital test wall held together by organic cement (agglutinated wall structure, also called arenaceous). The first calcareous walls appeared common in the Devonian, and modern porcellaneous and hyaline types became common from the Mesozoic. Benthic foraminifera are sensitive to water and sediment chemical characteristics, but their distribution patterns are also controlled by substrate type. Modern ecological studies commenced in the early 1950s, and the introduction of the Rose Bengal staining technique to differentiate tests with protoplasm from those lacking it was a landmark permitting a distinction between "living" and "non-living" specimens at the time of collection (Walton, 1952). The study of benthic foraminifera, their distributions and ecological features in recent sediment constitutes the basis to understand and interpret the fossil faunas (Murray, 1991). However, benthic foraminifera have not been studied in detail in many marine areas, including the Marmara Sea, and even less is known about the ecological preferences of the agglutinated species. Accordingly, the goal of this paper is to document, for the first time, the modern agglutinated foraminiferal fauna and their bathymetric distribution along an inner neritic to upper bathyal transect in the Marmara Sea, where strong environmental gradients are present. Moreover, this study aims at comparing the recognised agglutinated assemblages to water mass properties in the Marmara Sea, to establish the utility of agglutinated foraminifera as tracers of the water masses present.
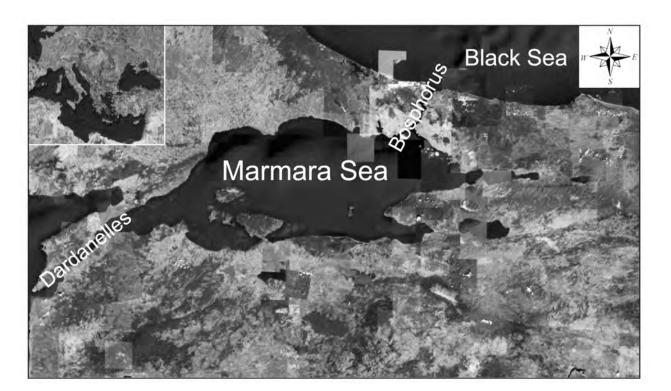
**Figure 1.** Satellite image of the Marmara Sea.

### Study area

The Marmara Sea is a small intercontinental basin situated between the world's largest permanently anoxic basin, the Black Sea, and the northeastern extension of the eastern Mediterranean basin, the Aegean Sea (Fig. 1). The Marmara Sea is characterised by a very complex morphology including shelves, slopes, basins, sub-basins and ridges. It occupies a transtensional basin situated along a set of en-echelon dextral strike-slip faults that forms part of the North Anatolian Transform Fault system (Aksu *et al.*, 2000). The Marmara Sea is connected to brackish waters of the Black Sea via the Bosporus Strait and to normal marine waters of the Mediterranean Sea via the Canakkale Strait (the Dardanelles). There are two sills at the Bosporus, one located off the northern entrance at a depth of about 60 m and the other one in the southern entrance at 30 m. Even though the Dardanelles strait reaches depths of ~100 m, several sills are present to contemporary depths of 60-70 m. These topographical features control the water exchange and bottom water circulation between the Aegean Sea and the Black Sea (Ergin *et al.*, 1997). The cooler and lower salinity (17-20 psu) water from the Black Sea flowing through the Bosphorus Strait enters the Marmara Sea as a surface current, whereas warmer and higher salinity (38-39 psu) deep water from the Marmara Sea flows northward as a counter-current. An identical two-way flow exists in the Dardanelles Strait, thereby establishing an overall estuarine circulation within the Marmara Sea. Consequently, the Marmara Sea is characterised by brackish shallow-water outflow from the Black Sea and saline deep-water saline inflow from the Mediterranean Sea. Under these oceanographic features, a sharp halocline is present in the Marmara Sea leading to low-oxygen and stratified conditions below a thin, well-mixed and more oxygenated surface layer (Kaminski *et al.*, 2002).

### Previous studies on benthic foraminifera from the Marmara Sea

Within the past decades numerous studies on modern benthic foraminifera have been conducted in the Mediterranean Sea (i.e., Parker, 1958; Cimerman & Langer, 1991; Sgarella & Moncharmont Zei, 1993, Basso & Spezzaferri, 2000; Rasmussen, 2005; Coccioni *et al.*, 2008) and in the Black Sea (Mikhalevich, 1969, 1994; Tufescu, 1973; Yanko & Troitskaja, 1987; Yanko, 1990; Temelkov *et al.*, 2006, Temelkov, 2008). These studies have focused on the diversity, spatial distribution and composition of foraminiferal assemblages including their ecology, bathymetric distribution and abundance. Accordingly, environmental and taxonomic investigations on benthic foraminifera from the Eastern Mediterranean and Aegean Sea have been carried out by Parker (1958). This work has been updated by Cimerman & Langer (1991) who taxonomically revised the modern foraminiferal species of the Mediterranean Sea and
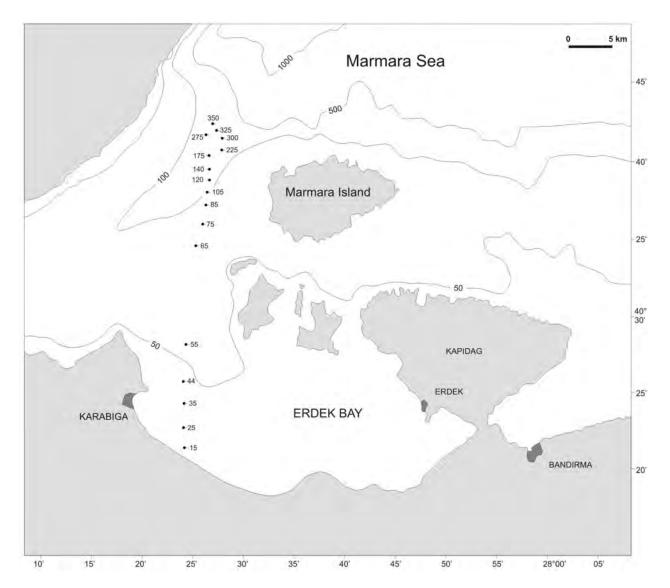
**Figure 2.** Location map of the study area with sampling stations collected along a transect from the Southern Marmara shelf during the MAR-02 Cruise.

produced a comprehensive and adequately illustrated monograph. This taxonomic framework has been expanded by Sgarrella & Moncharmont Zei (1993), who provided systematic and bathymetric distributions of 356 species recognised in the Gulf of Naples, and more recently by Rasmussen (2005), who investigated the systematic palaeontology and ecology of benthic foraminifera from the Plio-Pleistocene Kallithea Bay Section, Rhodes (Greece). Living benthic foraminifera in Iskenderun Bay (Turkey) have been explored by Basso & Spezzaferri (2000), who documented the relation between environmental parameters and distribution of benthic foraminifera through a statistical approach. An overview of the modern agglutinated foraminifera recognised in the Western Adriatic Sea during the last two decades together with some remarks on their ecology was provided by Coccioni *et al*. (2008) who documented the high diversity encountered in this area where

sixty-eight agglutinated species belonging to thirty-six genera were recognised.

Foraminiferal assemblages and their ecological features for the northwestern region of the Black Sea have been investigated by Tufescu (1973), who documented an impoverished fauna composed of only 50 benthic species (Murray, 1991). A total of 70 benthic foraminiferal species were documented by Yanko & Troitskaja (1987) in the same area. Their diversity, stratigraphy and ecology was summarised by Yanko (1990) who concluded that the modern Black Sea foraminiferal faunas essentially consist of Mediterranean immigrants. A brief historical review of the studies on the recent benthic foraminifera from the Bulgarian Black Sea Coast was presented by Temelkov *et al*. (2006) who highlighted the higher foraminiferal diversity of the Mediterranean compared with that of the Black Sea. According to these authors, this difference could be explained firstly by

the great difference of the salinity of the two areas, and secondly by the presence of H$_2$S in the Black Sea below 150-200 m water depth. An ecological characterisation of the foraminiferal fauna in the same area has been provided by Temelkov (2008).

Several studies have been carried out on benthic foraminifera from the Marmara Sea during the last two decades (Alavi, 1988; Meriç & Sakinç, 1990; Meriç *et al.*, 1995, 2005; Çağaty *et al.*, 1999, 2000; Kaminski *et al.*, 2002; Chendeş *et al.*, 2004; Meriç & Algan, 2007; Phipps, 2007; Spezzaferri & Yanko-Hombach, 2007; Kirci-Elmas *et al.*, 2007). Benthic foraminiferal assemblages were investigated in two cores recovered from the eastern depression of the Marmara Sea at 1200 m water depth by Alavi (1988). Alavi found a benthic foraminiferal assemblage rich in individuals, but poorly diversified when compared with other marginal basins. Moreover, agglutinated foraminifera were rare or absent, presumably due to their great sensitivity to oxygen-deficient conditions. In fact, only seven agglutinated foraminiferal species were recognised, including *Adercotryma glomerata*, *Trochammina* sp., *Spiroplectinella sagittula* (reported as *Textularia sagittula*), *Textularia* sp., *T. agglutinans*, *Bigenerina nodosaria*, and *Siphotextularia concava*. Benthic foraminiferal assemblages from the Marmara Sea were also studied from Upper Pliocene to Holocene geotechnical boreholes in the Gulf of Izmit by Meriç *et al.* (1995), from the southern exit of the Istanbul Strait by Meriç & Sakinç (1990) and from selected boreholes drilled in littoral areas by Meriç & Algan (2007). On the basis of these studies only three agglutinated species were recognised (*S. sagittula*, *T. bocki*, and *T. conica*). The first comprehensive study on benthic foraminifera was carried out by Kaminski *et al.* (2002) who investigated four gravity cores penetrating Holocene marine sediments in different environmental settings (delta, shelf, and sapropel). A total of 117 benthic foraminiferal species were found and the recovered assemblages showed strong affinities with those encountered in the Mediterranean Sea. These assemblages were however characterised by lower diversity and fewer organically cemented agglutinated foraminifera. In this study, nine agglutinated species were recognised (*B. nodosaria*, *T. bocki*, *T. conica*, *T. cushmani*, *T. stricta*, *T. truncata*, *Textularia* sp., *Siphotextularia* spp., and *Spirorutilus* spp.). Benthic foraminiferal assemblages in the sapropels were examined by Çağaty *et al.* (1999, 2000), although no agglutinated foraminifera were reported. An important study of modern benthic foraminiferal assemblages, along a thirty-sample transect collected from the southern shelf of the Marmara Sea, was carried out by Chendeş *et al.* (2004). They reported abundant, well-preserved and diverse faunas, recognising two distinct assemblages in the shallower and deeper parts of the study area. Large numbers of agglutinated foraminifera, such as *Ammoscalaria pseudospiralis*, *Reophax* sp., and *Lagenammina fusiformi*s, were recorded within the mixing zone between the two main water-masses of the Black Sea (shallower) and the Mediterranean Sea (deeper). Chendeş *et al.* (2004) also reported changes in abundance of *Spirorutilus* sp. and *B. nodosaria* below a depth of 140 m. *Eggerelloides scaber* (reported as *Eggerelloides scabrus*), *Reophax scorpiurus*, *T. cushmani* and *Textularia* sp. were among the other recognised agglutinated species. Meriç *et al.* (2005) analyzed 63 surface samples collected in the eastern part of the Marmara Sea, and recognised the following agglutinated species: *Rhabdammina abyssorum*, *Haplophragmoides* cf. *canariensis*, *Discammina compressa*, *S. sagittula* (reported as *Spiroplectammina sagittula*), *E. scaber* (reported as *E. scabrus*), *T. agglutinans*, *T. bocki*, *T. truncata*, and *S. concava*. Recently, Spezzaferri & Yanko-Hombach (2007) documented the speciation of *Hyalinea marmarica* from *H. balthica* after its migration from the Mediterranean Sea to the Marmara Sea between 14 and 12 ka.

Finally, a high-resolution micropalaeontological examination of two cores recovered from the central basin of the Marmara Sea was conducted by Kirci-Elmas *et al.* (2007), who reported the following agglutinated taxa: *E. scaber* (reported as *Eggerella scabra*), *B. nodosaria*, *Pseudoclavulina crustata*, *Siphotextularia* sp., *Spiroplectinella wrightii*, *T. bocki*, and *T. conica*.

On the basis of the foraminiferal assemblages recovered by Chendeş *et al.* (2004), a total of 211 calcareous benthic foraminiferal species were identified by Phipps (2007). The agglutinated component of the assemblages was not considered, and therefore form the basis of this study. Statistical treatment of the thirty-two most abundant species allowed the recognition of three clusters representing different environments. Moreover, by applying the Benthic Foraminiferal Oxygen Index (BFOI) of Kaiho (1991, 1994), Phipps was able to identify a summer oxygenated bottom current and speculated about the existence of two winter bottom currents. Evidence for the two winter bottom currents was found at 150-200 m and 275-350 m, associated with higher Fisher α index values, lower percentage dominance and increases in current derived winnowing. These data have been refined by Kaminski *et al.* (submitted), who determined discrepancies between calculated (BFOI) and measured oxygen values probably due to the seasonal influence of Mediterranean Inflow Water (MIW).

## MATERIAL AND METHODS

### Sampling

Thirty samples were collected on board the R/V Koca Piri Reis of the Institute of Marine Sciences and Technology, Dokuz Eylűl University, Izmir, Turkey during Cruise MAR-02 (Fig. 2). Samples were collected using a Shipeck grab sampling device along a transect from the southern shelf of the Marmara Sea in a bathymetric range of 15-350 m. On board, the grab sample was immediately and carefully opened in a container, where the sediment was deposited in its initial position. Surficial sediment was scraped from collected materials with a spoon, immediately washed through a 63$\mu$m sieve, and preserved in ethanol with Rose Bengal. There are a wide variety of methods that can be used to distinguish between living and non-living benthic foraminifera, and the choice of technique depends on the objectives of the study. The Rose Bengal method remains the most practical way of quantifying living foraminifera because it is quick and ideal for dealing with large numbers of samples (Murray, 2006). These samples are the same used by Chendeş *et al.* (2004) and Phipps (2007). At each station, temperature, salinity, dissolved oxygen (DO) of seawater were measured in vertical profile by means of CTD (Conductivity, Temperature and Depth) by Dogan Yaşar of the Institute of Marine Sciences and Technology, Dokuz Eylűl University, Izmir.

### Foraminiferal analysis

Samples were gently washed for a second time, dried, and split into aliquots using a modified Otto microsplitter. Seventeen samples were investigated for foraminiferal contents. Agglutinated benthic foraminifera were picked from the >125 $\mu$m fraction and mounted onto cardboard reference slides for counting. At least two hundred specimens, where possible, (total assemblages) were picked from each sample and taxonomically identified largely following both the generic classifications of Loeblich & Tappan (1987) and Kaminski *et al.* (2008) and specific classification of Cimerman & Langer (1991) and Sgarella & Moncharmont Zei (1993). Several foraminiferal parameters have been calculated including diversity indexes: species richness (S, number of species per sample), Fisher-$\alpha$ index (relationship between the number of species and the number of individuals in an assemblage, Fisher et al., 1943), and Shannon-Weaver index or information function (H') (Shannon & Weaver, 1963).

Other indexes have been considered: foraminiferal density (FD, number of specimens per 1g of dry sediment), Dominance (D), which ranges from 0 (all taxa are equally present) to 1 (one taxon dominates the community completely), and Equitability (J) used
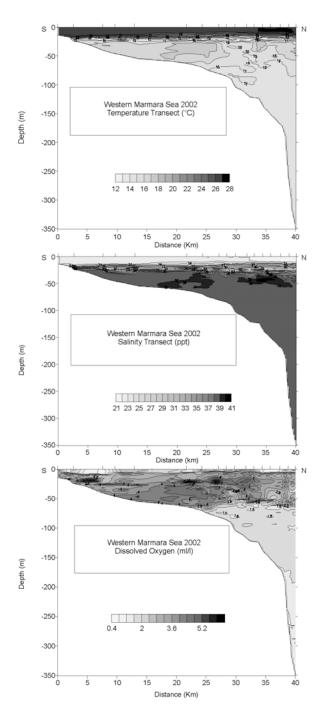


**Figure 3.** Vertical profiles of temperature (°C), salinity (g/l) and dissolved oxygen (ml/l) at 1-m depth intervals along the sampled transect in summer, 2002.

to describe how individuals are divided between species and calculated according to Pielou (1975). These indexes were calculated using the PAST – PAlaeontological STatistics data analysis package (version 1.68, Hammer *et al.,* 2001).

### Statistical analysis

Biological data were analyzed with multivariate techniques of Cluster Analysis (CA) and Corres-
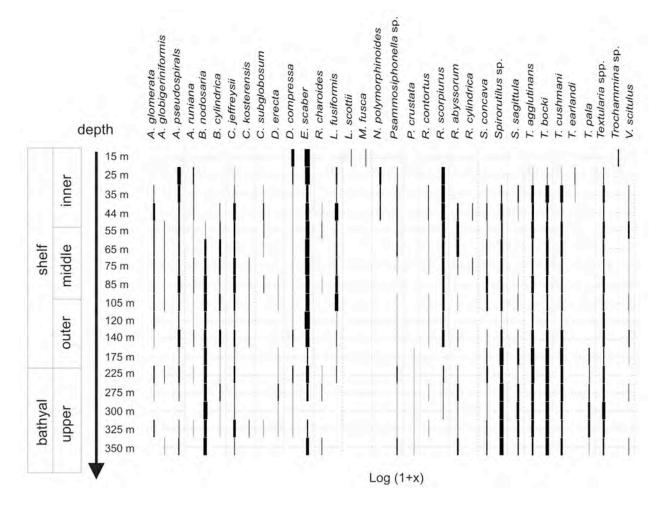
**Figure 4.** The bathymetric distributions of the most abundant taxa and their relative abundances are reported on a logarithmic scale.

pondence Analysis (COA), which were performed using the Windows SPSS 13.0 and Statistica 6.0 software. In order to reduce background 'noise', only species with a relative abundance greater than 1% in at least one sample were included in statistical treatment. Prior to statistical analysis, an additive logarithmic transformation log(1+X) was performed to remove the effects of orders of magnitude difference between variables, to normalise the data and to increase the importance of smaller values such as the mid-range species.

The classifications of stations (Q Mode CA) and species (R Mode CA) given in squared Euclidean distance, and Pearson correlation coefficient, respectively, were calculated by adopting the Ward's linkage method, which produces dendrograms with exceptionally well-defined clusters (Parker & Arnold, 1999).

The COA was used to determine the community's relationship to abiotic parameters. The COA attempts to identify the underlying factors that explain the pattern of correlation within a set of observed variables. It is used to reduce data in such a way as to identify a small number of factors that explain most

of the variance observed in a much larger number of manifested variables. It has also been used to better interpret the data by providing on the same plot both stations (cases) and species (variables).

## RESULTS
### *Hydrological features*
During the sampling, temperature (°C), salinity (g/l) and dissolved oxygen (ml/l) of seawater was measured in vertical profiles. These parameters are plotted against depth across the Marmara Sea transect (Fig. 3). Dissolved oxygen values measured at 1 m above the sea floor are reported in Appendix B. The water column shows a strongly stratified structure and five distinct hydrographical zones have been recognised. These zones are characterised as follows:

• **Zone 1.** The shallowest zone ranges from the surface down to ~15 m depth and represents homogeneous, brackish (22.6-22.8 g/l), warm, with oxygen values up to 4.3 ml/l. Its properties are indicative of outflow waters from the Black Sea.
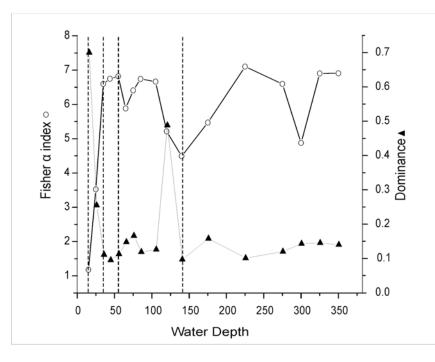
**Figure 5.** Comparison of Fisher-α index and Dominance values along the transect.

• **Zone 2.** This zone ranges from 15 m down to 30 m representing the pycnocline where rapidly temperature drops (25.8 to 19.8 °C) and salinity rises (22.8 to 37.9 g/l). A prominent increase in the oxygen content can be interpreted as the chlorophyll maximum zone most likely linked to photosynthetic activity. On the other hand, a drop in dissolved oxygen occurs below the pycnocline probably due to reduced mixing beneath the brackish shallow water layer.

• **Zone 3.** This zone down to 50 m is character-ised by a rise in dissolved oxygen levels with a peak of 4.09 ml/l at 50 m depth. A similar pattern is observed in temperature and salinity; this zone represents the summer inflow of the Mediterra-nean countercurrent.

• **Zone 4.** This zone ranges from 60 m down to 300 m depth and is represented by stable salinity conditions (38.6-38.8 g/l), and gradual declines in temperature (16.2-14.4 °C) and dissolved oxygen (3.79-1.09 ml/l).

• **Zone 5.** This zone is characterised by the same temperature and salinity as in Zone 4. Dissolved oxygen, however, shows a rise from 1.09 ml/l at 300 m to 1.42 ml/l at 325 m depth. This could be due to a bottom water undercurrent of Mediter-ranean origin leading to more oxygenated waters into the deeper end of the depth transect.

*Agglutinated foraminiferal distribution*
A total of 50 agglutinated benthic foraminiferal species belonging to 36 genera were identified in the total assemblage (Appendixes A and B). The relative abundance of recognised species varies from station to station, with only 34 species showing relative abundances greater than 1% in at least one.

The assemblages are largely dominated by *E. scaber* (24.9% on average), *Spirorutilus* sp. (10.4), *T. bocki* (9.3%), *B. nodosaria* (7.3%), *R. scorpiurus* (6.3%), *T. agglutinans* (5.8%) and *T. cushmani* (5.1%). The bathymetric distributions of the most abundant taxa and their relative abundances are shown in Figure 4. Accordingly, a few species, including *Discammina compressa*, *Lepthohalysis scottii*, *Miliammina fusca* and *Trochammina* sp., occur only in one sample at 15 m water depth, whereas they become rare or absent in all other sam-ples. Conversely, many agglutinated species show an intermediate water-depth distribution, among them the most abundant are *A. pseudospiralis*, *Cribrosto-moides jeffreysii*, *E. scaber*, *L. fusiformis*, and *R. scorpiurus*. Other species such as *B. nodosaria*, *P. crustata*, *S. concava*, *Spirorutilus* sp., *S. sagittula*, *T. agglutinans*, *T. bocki*, *T. cushmani* and *T. pala* show a deeper bathymetric distribution.

Along the transect, S varies from 5 (shallowest sample at 15 m depth) to 28 (at 105 m, 225 m, 275 m water depth) whereas FD shows a very complex pat-tern of distribution with the highest value at 105 m water depth. The Shannon–Weaver index varies from 0.6 (15 m depth) to 2.7 (140 m), J from 0.4 (15 m) to 0.82 (44 m and 140 m). The highest value of D occurs in the shallowest sample at 15 m depth whereas very low values are found downward. The
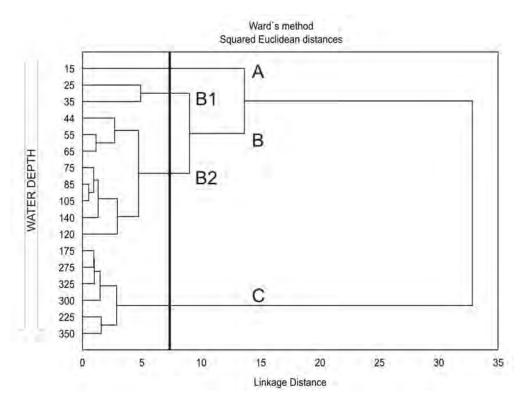
**Figure 6.** Dendrogram classification of stations produced by Q-mode cluster analysis using Euclidean distance.

Fisher-$\alpha$ index ranges from 1.2 (15 m) to 7.1 (225 m) (Appendix B). Values of D and the Fisher-$\alpha$ index have been plotted against water depth to reveal their variations (Fig. 5). The hydrological zones show the following faunal characteristics:

• **Zone 1.** The shallowest zone including only one station (15 m water depth) is characterised by both the lowest value of diversity and highest value of dominance. This zone is strongly related to hydrographical Zone 1 and consequently to the Black Sea water.

• **Zone 2.** This zone corresponding to the hydrographical Zone 2 shows a marked increase in the assemblages' diversity and a lowering in their dominance and it represents the pycnocline.

• **Zone 3.** This zone shows a further rise in diversity values and it can be correlated to the hydrographical Zone 3 representing the summer inflow of the Mediterranean countercurrent.

• **Zone 4.** This zone ranging from 50 m to 140 m water depth shows marked variations in its diversity values. These variations and their values are comparable with those found by Phipps (2007) who found the highest and lowest values of diversity among calcareous benthic foraminifera at 50 m and 150 m water depth, respectively. It also represents the quite stable temperature and salinity conditions and the gradual decline in

dissolved oxygen below the main body of summer Mediterranean water flowing into the Marmara Sea.

• **Zone 5.** A complex pattern of diversity occurs in this zone, which exhibits a rapid increase in diversity peaking at 225 m water depth. This zone is represented by stable salinity conditions and gradual declines in temperature and dissolved oxygen. The lowest value of diversity was recorded at 300 m water depth where also the lowest value of dissolved oxygen was found. A sharp increase in diversity values has been observed from 300 m to 350 m water depth which can be well correlated with a rise in dissolved oxygen probably due to a Mediterranean bottom water undercurrent.

*Statistical analysis*
The Q Mode CA results in the grouping of samples into three separates clusters (A, B, and C) according to their water depth (Fig. 6). The R Mode CA groups 'variables' which, in this case, are the relative abundance of species in relation to their distributional patterns (Fig. 7). Accordingly, this analysis enables us to better identify the bathymetric distribution of the recognised species. Cluster B can be subdivided into two sub-clusters (B1 and B2). Cluster A includes only one station at 15 m water depth, which is the
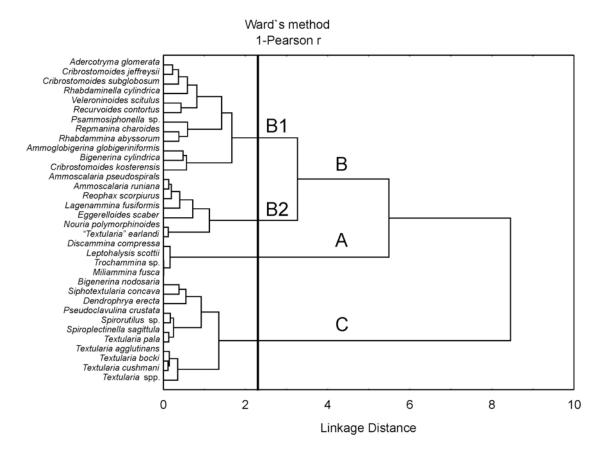
**Figure 7.** Dendrogram classification of species produced by R-mode cluster analysis using Euclidean distance.

shallowest; Cluster B comprises the intermediate stations ranging from 25 m to 140 m water depth, whereas Cluster C represents the deepest stations ranging from 140 m to 350 m water depth. Within Cluster B, the two recognised subclusters are separated between 35 and 44 m water depth. These clusters, calculated on the basis of the foraminiferal counts, may be interpreted as biofacies which reflect primarily different ecological conditions potentially influenced by substrate, organic matter availability, salinity and dissolved oxygen.

The COA bunched stations and species in approximately the same groups obtained with the Q and R Mode cluster analyses (Fig. 8). In addition, it allows us to identify the relation between the stations and species. Accordingly, three main groups have been identified. Group A is the most negative against Axis 1. On the other hand, Group B is positive against Axis 1 but negative against Axis 2. Group C is the most positive against Axis 1 and 2. On the basis of these patterns of distribution the Axis 1 can be interpreted as the water depth, whereas it is not clear which parameter(s) influence the Axis 2.

**DISCUSSION**

The spatial distribution of benthic foraminiferal assemblages is controlled by a combination of vari-

ous environmental parameters both biotic and abiotic (Murray 1991, 2006). The former includes competition for resources, space and food supply, whereas the biotic factors include temperature, salinity, dissolved oxygen, nutrients and sediment features. Accordingly, benthic foraminifera have been used as (paleo)oceanographic and (paleo)climatic proxies, although the interpretation of the past can be achieved only by understanding the present. Despite constituting a very peculiar basin in relation to its oceanographic features, the Marmara Sea has been poorly studied at least from a foraminiferal point of view. Foraminiferal assemblages are made up almost entirely of benthic species usually occurring in shelf environments. In particular, a total of 50 agglutinated species has been identified belonging to 36 genera. The relative abundances of the recognised species vary from station to station revealing their bathymetric distribution.

According to the statistical results, three main assemblages are recognised. Only 34 species showing relative abundances greater than 1% of the assemblage in at least one sample have been used for statistical analysis. The shallowest assemblage is largely dominated by few species including *D. compressa*, *L. scotti*, *M. fusca* and *Trochammina* sp., which become rare or absent in the other samples. *Discammina*
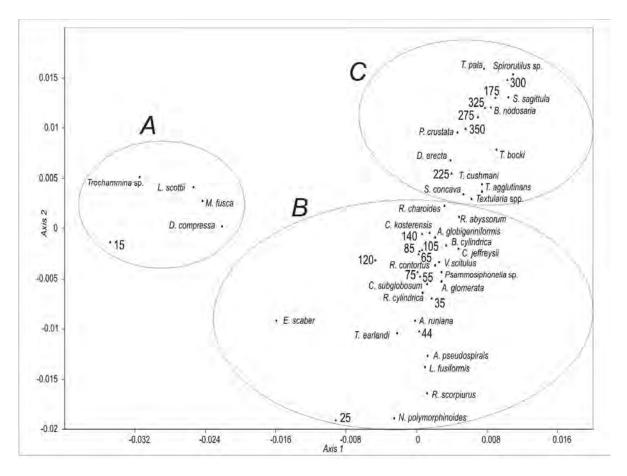
**Figure 8.** Correspondence analysis ordination diagram of stations and species.

*compressa* was reported in the Gulf of Naples from 72 m to 720 m by Sgarella & Moncharmont Zei (1993). *Lepthohalysis scotti* was recognised in front of the mouth of the Sarno and Rhône Rivers by Sgarella & Moncharmont Zei (1993) and Blanc-Vernet (1969), respectively. It was also found along the British coast in coastal muds in low energy environments (Murray, 1971). *Miliammina fusca* is restricted to brackish environments according to Cimerman & Langer (1991). *Trochammina* has been reported as rare and only in very shallow locations by Sgarella & Moncharmont Zei (1993) and in the Black Sea by Tufescu (1973). This assemblage is also characterised by both the lowest diversity and highest dominance values, no doubt induced by the strong influence exerted by the Black Sea outflow with its homogeneous, low salinity, and lower density waters where only a limited number of species can survive.

*Ammoscalaria pseudospiralis*, *"Textularia" earlandi*, *Nouria polymorphinoides* and several other agglutinated species characterise the upper intermediate assemblages, which also record an increase in their diversity values. The increased values of diversity was first identified by Phipps (2007) on the basis of calcareous foraminiferal assemblages and is associated with the inflow of a Mediterranean counter-current bringing more oxygenated and saline waters. *Ammoscalaria pseudospiralis* was reported in a wide range of environments from infralittoral (up to 50 m water depth) muddy sediments to the circalittoral (50-200 m water depth) zones (Sgarella & Moncharmont Zei, 1993). *"Textularia" earlandi* has been reported from circalittoral to infralittoral muddy sediments and from sandy sediments in front of the Rhône River between 15 and 80 m (Bizon & Bizon, 1984). *Nouria polymorphinoides* was recorded in the upper circalittoral zone in the Gulf of Naples by Sgarella & Moncharmont Zei (1993).

The lower intermediate assemblages down to ~150 m water depth is dominated by *Cribrostomoides jeffreysii*, *Veleroninoides scitulus*, *Recurvoides contortus*, *C. kosterensis*, *E. scaber*, *R. scorpiurus* and other accessory species. *Cribrostomoides jeffreysii* has been reported from infralittoral substrates. It was found in the Gulf of Naples between 10 m and 673 m and became more abundant down to 50 m (Sgarella & Moncharmont Zei, 1993). *Veleroninoides scitulus* was found both in muddy bathyal sediments by Blanc-Vernet (1969) and in the circalittoral to bathyal zone in the Gulf of Taranto (Iaccarino, 1969; Moncharmont Zei *et al.*, 1981). *Cribrostomoides kosterensis* was reported as highly

infrequent in the clay-belt in the Adriatic Sea by Jorissen *et al.* (1992). *Eggerelloides scaber* has been reported in many Mediterranean areas and as more frequent in infralittoral fine sands, sandy-muddy substrates and in the upper circalittoral zone (Sgarella & Moncharmont Zei, 1993). It was also reported as *Eggerella scabra* by de Stigter *et al.* (1998) from the shelf to uppermost slope zone in the Southern Adriatic Sea. *Eggerelloides scaber* increases in number below 70 m in the Black Sea, but it occurs even at 10 m water depth (Tufescu, 1973). This species (reported as *Eggerelloides scabrus*) was recognised in the Iskenderun Bay only in shallow samples by Basso & Spezzaferri (2000). However, it was recognised at ~900 m in the Marmara Sea by Kirci-Elmas *et al.* (2007). *Reophax scorpiurus* was identified in bathyal muds by Blanc-Vernet (1969). It occurred in the Gulf of Naples from 25 m to 490 m and became frequent deeper than 50 m (Sgarella & Moncharmont Zei, 1993). It was also recognised in the Iskenderun Bay with a median depth distribution below 50 m (Basso & Spezzaferri, 2000). These assemblages are characterised by generally high values of diversity that, however, decrease downward. This trend was also recognised by Phipps (2007) who related it to the declining values of dissolved oxygen.

The deep assemblages are dominated by *B. nodosaria*, *S. concava*, *Spirorutilus* spp., *S. sagittula*, *T. agglutinans*, *T. bocki*, *T. cushmani* and many other species. *Bigenerina nodosaria* was reported as common all around the Mediterranean in circalittoral and upper bathyal muds (Sgarella & Moncharmont Zei, 1993), and down to 799 m in the Eastern Mediterranean (Parker, 1958). It was also recognised from the shelf/upper slope to middle slope depth in the Southern Adriatic Sea by de Stigter *et al.* (1998). It was reported in large numbers below 140 m with a critical point at about 220 m depth in the Marmara Sea by Chendes *et al.* (2004), and from the same area by Kaminski *et al.* (2002). Although in very low numbers, this species has been recognised at ~900 m in the Marmara Sea by Kirci-Elmas *et al.* (2007). *Siphotextularia concava* was found from circalittoral and bathyal muds (Sgarella & Moncharmont Zei, 1993), and down to 631 m in the Eastern Mediterranean by (Parker, 1958). In the Marmara Sea, *Spirorutilus* spp. were reported in large numbers below 140 m with a critical point at about 220 m depth by Chendeş *et al.* (2004) and below 64 m by Kaminski *et al.* (2002). *Spiroplectinella sagittula* was reported as widespread in the Mediterranean in the infralittoral and circalittoral zones (Fiorini & Vaiani, 2001) and was recognised down to 166 m in the Adriatic Sea by Chierici *et al.* (1962). This species (reported as *Textularia sagittula*) was reported as common in shallow-shelf sediment from the Southern Adriatic Sea by de Stigter *et al.* (1998). It was also reported from the Marmara Sea at a water depth of 1200 m by Alavi (1988). *Textularia agglutinans* was documented as frequent in the circalittoral zone in the Gulf of Naples by Sgarella & Moncharmont Zei (1993) and in the infralittoral zone of the Venice Gulf by Jorissen (1988) and Albani & Serandrei Barbero, (1990). It was identified at 42 m in the Adriatic Sea by Chierici *et al.* (1962). A negative correlation between *T. agglutinans* and depth was found by Jorissen (1987, 1988), this species was also suggested to be a probable mud-dweller with a certain preference for a low input of clay (Jorissen, 1987, 1988). *Textularia bocki* was recognised in the Mediterranean from the infralittoral and circalittoral zones (Fiorini & Vaiani, 2001) and in the Iskenderun Bay with a median depth distribution below 50 m (Basso & Spezzaferri, 2000). *Rhabdammina abyssorum* was found to be abundant in bathyal muddy sediments by Blanc-Vernet (1969), and it occurred from 50 m downwards and became frequent deeper than 150 m in the Gulf of Naples (Sgarella & Moncharmont Zei, 1993).

The diversity values of these assemblages show a complex pattern, which exhibits a rapid increase and peaking at 225 m water depth. At a water depth of 300 m, the lowest diversity value corresponding to the minimum of dissolved oxygen has been recognised. Another increase in diversity values, also observed by Phipps (2007), has been found from 300 m to 350 m water depth linked to a rise in dissolved oxygen probably due to the presence of a Mediterranean bottom water undercurrent.

## CONCLUSIONS

For the first time, agglutinated benthic foraminifera have been investigated in detail in the Marmara Sea. The assemblages are highly diversified and contain 50 agglutinated species belonging to 36 genera. A multivariate statistical approach allows us to identify three main assemblages that can be partially related to the bathymetric depth and in turn to the hydrological features of water masses. The shallowest assemblage is characterised by both the lowest diversity and highest dominance values. These features result from the strong influence of the Black Sea outflow, with its homogeneous, low salinity, and lower density waters where only a limited number of species can survive. High diversity values are found at water depth shallower than 150 m, associated with the inflow of Mediterranean counter-current bringing more oxygenated and saline waters. The deep assemblages are dominated by *B. nodosaria*, *S. concava*, *Spirorutilus* spp., *S. sagittula*, *T. agglutinans*, *T. bocki*, and *T. cushmani* and their diversity values

exhibit a rapid increase and peak at 225 m water depth. On the other hand, the lowest value, which also corresponds to the lowest value of dissolved oxygen, was found at 300 m water depth. The diversity increase observed from 300 m to 350 m depth could be linked to a rise in dissolved oxygen probably due to the presence of a seasonal Mediterranean bottom water undercurrent.

## ACKNOWLEDGEMENTS

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Appendix A. Faunal reference list.

|  | Family | Genera | Species |
|---|---|---|---|
| Ammodiscina | Ammodiscidae | *Ammodiscus* | *Ammodiscus planorbis* |
|  |  | *Ammolagena* | *Ammolagena clavata* |
|  |  | *Repmanina* | *Repmanina charoides* |
|  |  | *Glomospira* | *Glomospira gordialis* |
|  |  | *Turritellella* | *Turritellella* sp. |
| Astrorhizina | Astrorhizacea | *Psammosiphonella* | *Psammosiphonella* sp. |
|  |  | *Rhabdammina* | *Rhabdammina abyssorum* |
|  |  | *Rhabdaminella* | *Rhabdaminella cylindrica* |
|  |  |  | *Rhabdaminella* sp. |
|  |  | *Dendrophrya* | *Dendrophrya erecta* |
| Hormosinina | Hormosinacea | *Reophax* | *Reophax dentaliniformis* |
|  |  |  | *Reophax scorpiurus* |
|  |  | *Leptohalysis* | *Leptohalysis scottii* |
|  |  | *Hormosina* | *Hormosina* sp |
| Lituolina | Lituolacea | *Ammoscalaria* | *Ammoscalaria pseudospirals* |
|  |  |  | *Ammoscalaria runiana* |
|  |  |  | *Ammoscalaria tenuimargo* |
|  |  | *Discammina* | *Discammina compressa* |
|  |  | *Haplophragmoides* | *Haplophragmoides bradyi* |
|  |  | *Veleroninoides* | *Veleroninoides scitulus* |
|  | Recurvoidacea | *Cribrostomoides* | *Cribrostomoides jeffreysii* |
|  |  |  | *Cribrostomoides kosterensis* |
|  |  |  | *Cribrostomoides subglobosum* |
|  |  | *Recurvoides* | *Recurvoides contortus* |
| Rzehakinina | Rzehakinidae | *Miliammina* | *Miliammina fusca* |
| Saccamminina | Saccaminacea | *Lagenammina* | *Lagenammina fusiformis* |
|  |  | *Saccammina* | *Saccammina* sp. |
| Spiroplectamminina | Spiroplectamminacea | *Spiroplectinella* | *Spiroplectinella sagittula* |
|  |  | *Nouria* | *Nouria polymorphinoides* |
|  |  | *Morulaeplecta* | *Morulaeplecta* sp. |
| Textulariina | Eggerellacea | *Eggerella* | *Eggerella propinqua* |
|  |  | *Connemarella* | *Connemarella rudis* |
|  |  | *Clavulina* | *Clavulina* sp. |
|  |  | *Pseudoclavulina* | *Pseudoclavulina crustata* |
|  | Textulariacea | *Bigenerina* | *Bigenerina nodosaria* |
|  |  |  | *Bigenerina cylindrica* |
|  |  | *Siphotextularia* | *Siphotextularia concava* |
|  |  |  | *Siphotextularia* sp. |
|  |  | *Spirorutilus.* | *Spirorutilus* sp. |
|  |  | *Textularia* | *Textularia agglutinans* |
|  |  |  | *Textularia bocki* |
|  |  |  | *Textularia cushmani* |
|  |  |  | *"Textularia" earlandi* |
|  |  |  | *Textularia pala* |
|  |  |  | *Textularia pseudorugosa* |
|  |  |  | *Textularia* spp. |
| Trochamminina | Adercotrymidae | *Adercotryma* | *Adercotryma glomerata* |
|  | Trochamminidae | *Ammoglobigerina* | *Ammoglobigerina globigeriniformis* |
|  |  | *Trochammina* | *Trochammina* sp. |
| Verneuilinina | Prolixoplectidae | *Eggerelloides* | *Eggerelloides scaber* |

**Appendix B.** Dissolved Oxygen content (ml/l) measured at 1 m above sea floor and relative and absolute abundances of agglutinated species and faunal parameters.

Appendix B

Sampling stations (water depth) and Dissolved Oxygen (ml/l): 15 (3.95), 25 (4.10), 35 (3.50), 44 (3.85), 55 (3.70), 65 (2.45), 75 (1.85), 85 (1.80), 105 (1.75), 120 (1.70), 140 (1.65), 175 (1.40), 225 (1.25), 275 (1.23), 300 (1.09), 325 (1.42), 350 (1.25). Each station reports count (n) and relative abundance (%).

| Species | 15 n | 15 % | 25 n | 25 % | 35 n | 35 % | 44 n | 44 % | 55 n | 55 % | 65 n | 65 % | 75 n | 75 % | 85 n | 85 % | 105 n | 105 % | 120 n | 120 % | 140 n | 140 % | 175 n | 175 % | 225 n | 225 % | 275 n | 275 % | 300 n | 300 % | 325 n | 325 % | 350 n | 350 % |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Adercotryma glomerata | 0 | 0.0 | 0 | 0.0 | 3 | 1.2 | 22 | 6.1 | 6 | 2.0 | 8 | 2.8 | 6 | 1.9 | 5 | 1.6 | 8 | 1.8 | 12 | 1.6 | 12 | 0.8 | 0 | 0.0 | 8 | 2.2 | 4 | 0.9 | 0 | 0.0 | 5 | 1.5 | 0 | 0.0 |
| Ammodiscus planorbis | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 3 | 0.8 | 4 | 0.9 | 0 | 0.0 | 2 | 0.9 | 2 | 0.9 |
| Ammoglobigerina globigeriniformis | 0 | 0.0 | 1 | 0.1 | 0 | 0.0 | 0 | 0.0 | 4 | 1.3 | 2 | 0.7 | 4 | 1.3 | 2 | 0.6 | 3 | 0.7 | 1 | 0.1 | 4 | 0.3 | 0 | 0.0 | 3 | 0.8 | 1 | 0.2 | 0 | 0.0 | 1 | 0.3 | 1 | 0.5 |
| Ammolagena clavata | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 1 | 0.3 | 2 | 0.4 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 |
| Ammoscalaria pseudospiralis | 0 | 0.0 | 183 | 17.9 | 25 | 10.2 | 14 | 3.9 | 8 | 2.6 | 7 | 2.4 | 12 | 3.9 | 18 | 5.8 | 15 | 3.4 | 14 | 1.8 | 91 | 6.2 | 3 | 0.7 | 9 | 2.5 | 5 | 1.1 | 0 | 0.0 | 2 | 0.6 | 4 | 1.9 |
| Ammoscalaria runiana | 0 | 0.0 | 17 | 1.7 | 2 | 0.8 | 3 | 0.8 | 1 | 0.3 | 2 | 0.7 | 3 | 1.0 | 3 | 1.0 | 2 | 0.5 | 5 | 0.7 | 19 | 1.3 | 3 | 0.7 | 1 | 0.3 | 0 | 0.0 | 0 | 0.0 | 1 | 0.3 | 0 | 0.0 |
| Ammoscalaria tenuimargo | 0 | 0.0 | 3 | 0.3 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 2 | 0.5 | 0 | 0.0 | 6 | 0.4 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 2 | 0.6 | 0 | 0.0 |
| Bigenerina cylindrica | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 5 | 1.4 | 8 | 2.6 | 15 | 5.2 | 12 | 3.9 | 3 | 1.0 | 14 | 3.2 | 9 | 1.2 | 73 | 5.0 | 3 | 0.7 | 0 | 0.0 | 7 | 1.5 | 2 | 0.7 | 2 | 0.6 | 0 | 0.0 |
| Bigenerina nodosaria | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 2 | 0.7 | 18 | 6.3 | 15 | 4.8 | 30 | 9.6 | 43 | 9.8 | 32 | 4.2 | 116 | 7.9 | 46 | 10.6 | 42 | 11.7 | 54 | 11.9 | 58 | 20.0 | 36 | 10.7 | 35 | 16.2 |
| Clavulina sp. | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 |
| Connemarella rudis | 0 | 0.0 | 5 | 0.5 | 3 | 1.2 | 28 | 7.7 | 13 | 4.3 | 7 | 2.4 | 18 | 5.8 | 21 | 6.7 | 19 | 4.3 | 10 | 1.3 | 55 | 3.8 | 5 | 1.1 | 11 | 3.1 | 6 | 1.3 | 2 | 0.7 | 22 | 6.5 | 3 | 1.4 |
| Cribrostomoides jeffreysii | 0 | 0.0 | 3 | 0.3 | 1 | 0.4 | 6 | 1.7 | 1 | 0.3 | 1 | 0.3 | 3 | 1.0 | 4 | 1.3 | 3 | 0.7 | 8 | 1.0 | 17 | 1.2 | 1 | 0.2 | 1 | 0.3 | 0 | 0.0 | 0 | 0.0 | 1 | 0.3 | 0 | 0.0 |
| Cribrostomoides kosterensis | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 1 | 0.3 | 1 | 0.3 | 1 | 0.3 | 0 | 0.0 | 1 | 0.2 | 0 | 0.0 | 3 | 0.2 | 0 | 0.0 | 1 | 0.3 | 0 | 0.0 | 0 | 0.0 | 1 | 0.3 | 1 | 0.3 |
| Cribrostomoides subglobosum | 0 | 0.0 | 1 | 0.0 | 1 | 0.4 | 6 | 1.7 | 2 | 0.7 | 0 | 0.0 | 0 | 0.0 | 4 | 1.3 | 1 | 0.2 | 8 | 1.0 | 17 | 1.2 | 1 | 0.2 | 0 | 0.0 | 7 | 1.5 | 0 | 0.0 | 1 | 0.3 | 0 | 0.0 |
| Dendrophrya erecta | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 |
| Discammina compressa | 10 | 12.3 | 14 | 1.4 | 1 | 0.4 | 1 | 0.3 | 2 | 0.7 | 2 | 0.7 | 1 | 0.3 | 1 | 0.3 | 3 | 0.7 | 7 | 0.9 | 26 | 1.8 | 2 | 0.5 | 2 | 0.6 | 2 | 0.4 | 1 | 0.3 | 2 | 0.6 | 0 | 0.0 |
| Eggerella propinqua | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 1 | 0.1 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 |
| Eggerelloides scaber | 67 | 82.7 | 430 | 42.0 | 20 | 8.2 | 66 | 18.2 | 80 | 26.5 | 98 | 34.0 | 115 | 37.0 | 88 | 28.2 | 127 | 28.9 | 526 | 69.3 | 335 | 22.9 | 7 | 1.6 | 32 | 8.9 | 17 | 3.8 | 0 | 0.0 | 6 | 1.8 | 21 | 9.7 |
| Glomospira gordialis | 0 | 0.0 | 0 | 0.0 | 2 | 0.8 | 1 | 0.3 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 2 | 0.5 | 3 | 0.4 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 2 | 0.4 | 0 | 0.0 | 2 | 0.9 | 2 | 0.9 |
| Haplophragmoides bradyi | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 1 | 0.3 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 1 | 0.1 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 |
| Hormosina sp. | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 |
| Lagenammina fusiformis | 0 | 0.0 | 44 | 4.3 | 3 | 1.2 | 48 | 13.3 | 10 | 3.3 | 6 | 2.1 | 13 | 4.2 | 24 | 7.7 | 54 | 12.3 | 3 | 0.4 | 27 | 1.8 | 2 | 0.5 | 5 | 1.4 | 0 | 0.0 | 0 | 0.0 | 4 | 1.4 | 0 | 0.0 |
| Leptohalysis scottii | 1 | 1.2 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 |
| Miliammina fusca | 1 | 1.2 | 1 | 0.1 | 1 | 0.4 | 6 | 1.7 | 2 | 0.7 | 1 | 0.3 | 0 | 0.0 | 1 | 0.3 | 3 | 0.7 | 7 | 0.9 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 7 | 1.5 | 1 | 0.4 | 1 | 0.3 | 0 | 0.0 |
| Morulaeplecta sp. | 0 | 0.0 | 2 | 0.2 | 1 | 0.4 | 1 | 0.3 | 1 | 0.3 | 2 | 0.7 | 1 | 0.3 | 1 | 0.3 | 1 | 0.2 | 2 | 0.2 | 2 | 0.1 | 1 | 0.2 | 3 | 0.7 | 3 | 0.7 | 3 | 1.0 | 3 | 0.9 | 1 | 0.5 |
| Nouria polymorphinoides | 0 | 0.0 | 67 | 6.5 | 7 | 2.9 | 8 | 2.2 | 6 | 2.0 | 7 | 2.4 | 0 | 0.0 | 2 | 0.6 | 4 | 0.9 | 3 | 0.4 | 2 | 0.1 | 1 | 0.2 | 5 | 1.4 | 2 | 0.4 | 2 | 0.7 | 2 | 0.6 | 4 | 1.9 |
| Psammosiphonella sp. | 0 | 0.0 | 12 | 1.2 | 5 | 2.0 | 10 | 2.8 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 1 | 0.3 | 2 | 0.7 | 2 | 0.4 | 1 | 0.3 | 3 | 0.9 | 2 | 0.9 |
| Pseudoclavulina crustata | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 |
| Recurvoides contortus | 0 | 0.0 | 0 | 0.0 | 3 | 1.2 | 4 | 1.1 | 1 | 0.3 | 0 | 0.0 | 2 | 0.6 | 0 | 0.0 | 1 | 0.2 | 2 | 0.3 | 5 | 0.3 | 3 | 0.7 | 3 | 0.7 | 3 | 0.7 | 4 | 1.4 | 0 | 0.0 | 0 | 0.0 |
| Reophax dentaliniformis | 0 | 0.0 | 4 | 0.4 | 1 | 0.4 | 2 | 0.6 | 0 | 0.0 | 0 | 0.0 | 2 | 0.6 | 0 | 0.0 | 1 | 0.2 | 2 | 0.2 | 5 | 0.1 | 1 | 0.2 | 2 | 0.7 | 0 | 0.0 | 0 | 0.0 | 2 | 0.9 | 0 | 0.0 |
| Reophax scorpiurus | 0 | 0.0 | 205 | 20.0 | 43 | 17.6 | 55 | 15.2 | 39 | 12.9 | 23 | 8.0 | 29 | 9.3 | 15 | 4.8 | 23 | 5.2 | 21 | 2.8 | 95 | 6.5 | 1 | 0.2 | 7 | 1.9 | 3 | 0.7 | 4 | 1.4 | 1 | 0.3 | 0 | 0.0 |
| Repmanina charoides | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 1 | 0.3 | 4 | 1.3 | 0 | 0.0 | 0 | 0.0 | 1 | 0.3 | 2 | 0.5 | 3 | 0.4 | 0 | 0.0 | 1 | 0.2 | 2 | 0.6 | 4 | 0.9 | 0 | 0.0 | 3 | 0.9 | 3 | 1.4 |
| Rhabdammina abyssorum | 0 | 0.0 | 0 | 0.0 | 5 | 2.0 | 15 | 4.1 | 21 | 7.0 | 19 | 6.6 | 3 | 1.0 | 0 | 0.0 | 2 | 0.5 | 3 | 0.4 | 12 | 0.8 | 8 | 1.8 | 5 | 1.4 | 16 | 3.5 | 2 | 0.7 | 4 | 1.2 | 6 | 2.8 |
| Rhabdammina cylindrica | 0 | 0.0 | 0 | 0.0 | 1 | 0.4 | 5 | 1.4 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 |
| Rhabdaminella sp. | 0 | 0.0 | 3 | 0.3 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 |
| Saccammina sp. | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 1 | 0.3 | 0 | 0.0 | 1 | 0.2 | 1 | 0.1 | 0 | 0.0 | 1 | 0.2 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 1 | 0.5 |
| Siphotextularia concava | 0 | 0.0 | 5 | 0.5 | 1 | 0.4 | 5 | 1.4 | 3 | 1.0 | 4 | 1.4 | 6 | 1.9 | 15 | 4.8 | 14 | 3.2 | 1 | 0.1 | 14 | 1.0 | 8 | 1.8 | 10 | 2.8 | 5 | 1.1 | 3 | 1.0 | 8 | 2.4 | 3 | 1.4 |
| Siphotextularia sp. | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 2 | 0.6 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 |
| Spiroplectinella sagittula | 0 | 0.0 | 5 | 0.5 | 3 | 1.2 | 17 | 4.7 | 10 | 3.3 | 11 | 3.8 | 11 | 3.5 | 12 | 3.8 | 26 | 5.9 | 7 | 0.9 | 21 | 1.4 | 19 | 4.4 | 40 | 11.1 | 27 | 6.0 | 18 | 6.2 | 17 | 5.0 | 4 | 1.9 |
| Spirorutilus sp. | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 |
| Textularia agglutinans | 0 | 0.0 | 5 | 0.5 | 24 | 9.8 | 19 | 5.2 | 20 | 6.6 | 10 | 3.5 | 11 | 4.2 | 17 | 5.4 | 18 | 4.1 | 23 | 3.0 | 121 | 8.3 | 53 | 11.4 | 41 | 11.4 | 34 | 7.5 | 22 | 7.6 | 23 | 6.8 | 6 | 2.8 |
| Textularia bocki | 0 | 0.0 | 6 | 0.6 | 41 | 16.8 | 9 | 2.5 | 15 | 5.0 | 21 | 7.3 | 18 | 5.8 | 15 | 4.8 | 14 | 3.2 | 19 | 2.5 | 106 | 7.2 | 85 | 19.5 | 74 | 20.6 | 67 | 14.8 | 52 | 17.9 | 52 | 15.4 | 32 | 14.8 |
| Textularia cushmani | 0 | 0.0 | 2 | 0.2 | 33 | 13.5 | 6 | 1.7 | 18 | 6.0 | 15 | 5.2 | 12 | 3.9 | 12 | 3.8 | 16 | 3.6 | 12 | 1.6 | 99 | 6.8 | 50 | 11.5 | 26 | 7.2 | 33 | 7.3 | 12 | 4.1 | 13 | 3.8 | 12 | 5.6 |
| "Textularia" earlandi | 0 | 0.0 | 11 | 1.1 | 1 | 0.4 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 9 | 2.1 | 4 | 1.1 | 3 | 0.7 | 12 | 4.1 | 14 | 4.1 | 2 | 0.9 |
| Textularia pala | 0 | 0.0 | 0 | 0.0 | 1 | 0.4 | 2 | 0.6 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 1 | 0.2 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 2 | 0.6 | 0 | 0.0 |
| Textularia pseudorugosa | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 1 | 0.2 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 |
| Textularia spp. | 0 | 0.0 | 10 | 1.0 | 14 | 5.7 | 5 | 1.4 | 15 | 5.0 | 9 | 3.1 | 8 | 2.6 | 15 | 4.8 | 14 | 3.2 | 34 | 4.5 | 75 | 5.1 | 12 | 2.8 | 15 | 4.2 | 20 | 4.4 | 35 | 12.1 | 12 | 3.6 | 7 | 3.2 |
| Trochammina sp. | 2 | 2.5 | 0 | 0.0 | 0 | 0.0 | 5 | 1.4 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 1 | 0.2 | 1 | 0.3 | 0 | 0.0 | 0 | 0.0 |
| Turrilelliella sp. | 0 | 0.0 | 0 | 0.0 | 2 | 0.8 | 5 | 1.4 | 10 | 3.3 | 1 | 0.3 | 2 | 0.6 | 1 | 0.3 | 3 | 0.7 | 2 | 0.3 | 23 | 1.6 | 1 | 0.3 | 0 | 0.0 | 4 | 0.9 | 1 | 0.3 | 2 | 0.9 | 2 | 0.9 |
| Veleroninoides scitulus | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 |

Faunal parameters

| Parameter | 15 | 25 | 35 | 44 | 55 | 65 | 75 | 85 | 105 | 120 | 140 | 175 | 225 | 275 | 300 | 325 | 350 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Foraminiferal Density (FD) | 24.2 | 432.5 | 73.7 | 202.2 | 3020.0 | 146.9 | 3887.5 | 2836.4 | 8780.0 | 438.7 | 920.8 | 550.6 | 2564.3 | 141.6 | 805.6 | 108.3 | 57.1 |
| Species Richness (S) | 5 | 20 | 24 | 27 | 26 | 23 | 25 | 26 | 28 | 26 | 26 | 24 | 28 | 28 | 20 | 27 | 24 |
| Dominance (D) | 0.70 | 0.25 | 0.11 | 0.10 | 0.11 | 0.15 | 0.17 | 0.12 | 0.13 | 0.49 | 0.10 | 0.16 | 0.10 | 0.12 | 0.14 | 0.15 | 0.14 |
| Shannon-Weaver (H) | 0.62 | 1.76 | 2.49 | 2.70 | 2.64 | 2.46 | 2.43 | 2.58 | 2.58 | 1.46 | 2.68 | 2.19 | 2.65 | 2.54 | 2.20 | 2.41 | 2.41 |
| Simpson (1-D) | 0.30 | 0.75 | 0.89 | 0.90 | 0.89 | 0.85 | 0.83 | 0.88 | 0.87 | 0.51 | 0.90 | 0.84 | 0.90 | 0.88 | 0.86 | 0.85 | 0.86 |
| Evenness e^H/S | 0.37 | 0.29 | 0.50 | 0.55 | 0.54 | 0.51 | 0.46 | 0.51 | 0.47 | 0.17 | 0.56 | 0.37 | 0.50 | 0.45 | 0.45 | 0.41 | 0.46 |
| Equitability (J) | 0.38 | 0.59 | 0.78 | 0.82 | 0.81 | 0.79 | 0.76 | 0.79 | 0.77 | 0.45 | 0.82 | 0.69 | 0.79 | 0.76 | 0.74 | 0.73 | 0.76 |
| Fisher α index | 1.18 | 3.52 | 6.60 | 6.75 | 6.82 | 5.88 | 6.41 | 6.74 | 6.66 | 5.21 | 4.49 | 5.47 | 7.10 | 6.60 | 4.88 | 6.90 | 6.91 |

**Plate 1. 1.** *Psammosiphonella* sp. 35m; **2.** *Rhabdamminella* sp. 25m; **3.** *Lagenammina fusiformis*, 25m; **4.** *Glomospira gordialis*, 44m; **5.** *Repmanina charoides*, 44m; **6.** *Reophax dentaliniformis*, 44 m; **7.** *Reophax scorpiurus*, 44m; **8.** *Miliammina fusca*, 15 m; **9.** *Haplophragmoides bradyi*, 55m; **10.** *Veleroninoides scitulus*, 55m; **11.** *Ammoscalaria pseudoscalaris*. 75m; **12.** *Ammoscalaria runiana* 25m; **13.** *Cribrostomoides kosternensis*, 75m; **14.** *Recurvoides contortus*, 44m; **15.** *Adercotryma glomerata*, 44m; **16.** *Trochammina* sp. 15m; **17.** *"Textularia" earlandi*, 25m; **18.** *Morulaeplecta* sp. 25m; **19.** *Eggerelloides scaber*, 15m; **20.** *Siphotextularia concava*, 175m; **21.** *Textularia* sp. 75m; **22.** *Textularia pala* 175m; **23.** *Spirorutilus* sp. 85m.